Design Considerations Using Quartz Crystals with Zilog's Components

Application Note

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INTRODUCTION

Many times, the designer of microprocessor-based systems has considerable expertise in digital logic design but knows little about analog circuits. This designer needs to know about crystal operation with microprocessors because a crystal in conjunction with an oscillator (on-chip/off-chip) provides the clock to the microprocessor. This application note is intended to answer simple questions about the operation of crystals and their use with Zilog's components.

BRIEF THEORY ON CRYSTALS

A quartz crystal is a piezoelectric device that transforms electrical energy into mechanical energy. When an electrical potential is applied to the quartz crystal, it starts oscillating at a frequency dependent on the characteristics of the crystal.

The schematic representation of a simple quartz crystal is shown in Figure 1. The equivalent circuit of the crystal is shown in Figure 2.

In Figure 2, L represents the motional inductance as a result of the motion of the mechanical mass; this is similar to mechanical resonators. C represents motional capacitance while R represents motional resistance. Cs, the shunt capacitance, is the electrostatic capacitance due to the crystal electrodes, with the quartz plates as a dielectric. The value of the capacitance Cs depends on the area and thickness of the quartz plates. Cs also depends on contact wires, the crystal holder, and the angle of cut from the mother crystal. These cuts are chosen to optimize the temperature coefficient, the frequency range, and other crystal parameters.

The performance of the crystal is dependent on mechanical and electrical characteristics. The mechanical characteristics include the method of lead attachment, package sealing method, and internal environment (e.g., vacuum, partial pressure, etc.). The electrical characteristics include load capacitance, crystal resistance, drive level, temperature coefficient/turning point, and frequency tolerance.

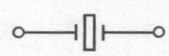

Figure 1. Schematic Representation of Quartz Crystal

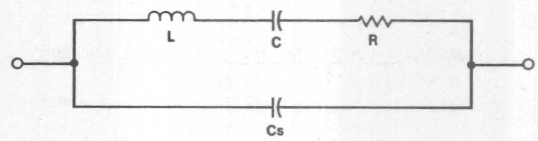

Figure 2. Equivalent Circuit of Quartz Crystal

SERIES RESONANCE AND PARALLEL RESONANCE

Manufacturers of crystals specify crystals as either series-resonant or parallel-resonant (Figure 3).

At the frequency of series resonance:

$$fs = \frac{1}{2\pi\sqrt{L*C}}$$

When the magnitude of X_C (reactance of C) and X_L (reactance of L) are equal, one effectively cancels the other, resulting in an equivalent of R shunted by Cs. If R is very small compared to X_{Cs}, series resonance is indicated by minimum impedance and zero phase shift. The series-resonant crystals are resistive and produce an output in phase with the input.

At frequencies slightly higher than series resonance, X_L increases and X_C decreases, resulting in a net inductive reactance, X_L. When $X_L = X_{Cs}$, the result is parallel resonance with the frequency of parallel resonance:

$$fp = \frac{1}{2\pi\sqrt{L*\frac{C*C_s}{C+C_s}}}$$

Parallel resonance is indicated by maximum impedance across the crystal terminals. Parallel-resonant crystals are inductive and produce the output shifted in phase from the input.

If a series crystal is used with a parallel-resonant oscillator, the crystal is forced to operate in the parallel region (and vice versa). The clock frequency produced is shifted a small percentage (about 350 ppm) from the specified series crystal frequency (Figure 3). Any attempts to fine tune the frequency by changing the value of external capacitance may cause the crystal to stop oscillating.

From the equivalent circuit of the crystal and the expression of fs, it can be seen that the series-resonant frequency of the crystal cannot be changed by reactance across the crystal terminals because there is no connection to the junction of L and C. In the case of parallel resonant frequency, Cs appears in the expression and its effective value can be changed by reactance across the terminals.

The load capacitance (C_L) is the capacitance that the crystal sees at its terminals. In parallel-resonant mode, load capacitance is very important, because C_L in combination with crystal inductance determines the frequency.

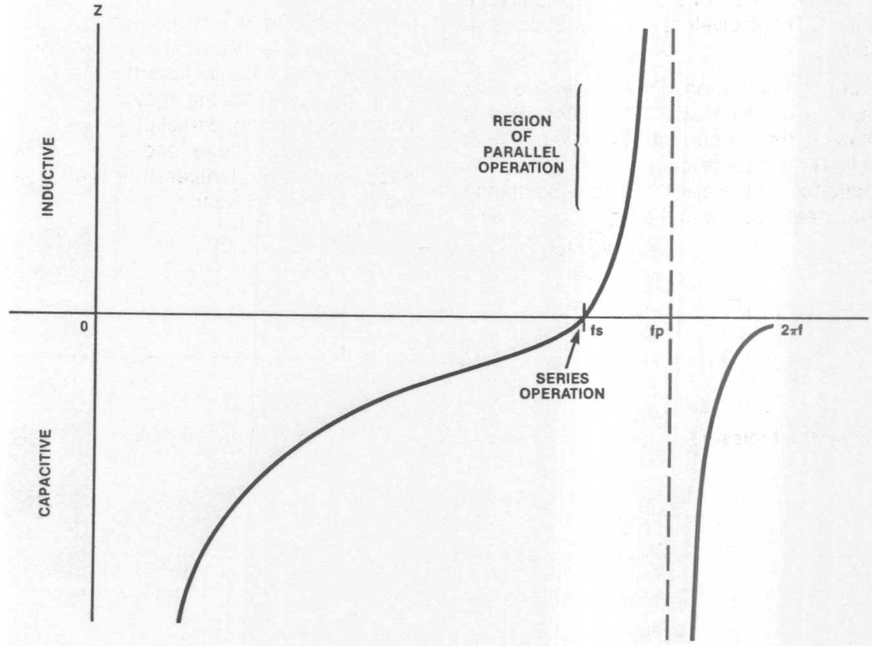

Figure 3. Series vs. Parallel Resonance

Crystal selection is based on the oscillator design used to provide the clock to the system. Series-resonant crystals should be used with non-inverting oscillators because series-resonant crystals have no phase shift. Parallel-resonant crystals should be used with inverting oscillators because parallel-resonant crystals have some phase shift due to their inductive nature.

DRIVE LEVEL

Drive level is critical because the crystal can dissipate only limited power (10 mW typical) and still meet all specifications. Overdrive may cause the temperature to rise in the crystal. Further overdrive may cause the quartz to operate in a non-linear region producing a frequency shift and possibly causing permanent damage to the crystal.

SERIES CONFIGURATION

When the internal oscillator is non-inverting, the recommended crystal is series-resonant and the circuit diagram shown in Figure 4 is used.

Many supposedly series-resonant IC oscillators actually operate below series resonance. C1 is used to compensate for this inductive nature of the series-type oscillator. C1 provides enough capacitive reactance to cancel the inductive shift caused by the IC. This brings the overall frequency back to series resonance.

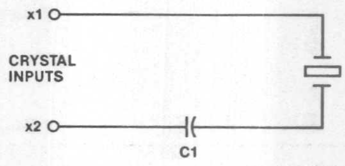

Figure 4. Circuit for Series-Resonant Crystals

PARALLEL CONFIGURATION

When the internal oscillator is inverting, the recommended crystal is parallel-resonant and the circuit diagram shown in Figure 5 is used.

The load capacitance, C_L, is determined by the following equation:

$$C_L = \frac{C_1 * C_2}{C_1 + C_2} + C_C$$

where C_C is the parasitic circuit capacitance.

The parallel resonance frequency is determined by the following equation:

$$fp = \frac{1}{2\pi \sqrt{L^* \dfrac{C^* C_t}{C + C_t}}}$$

where $C_t = C_L + C_S$

Typically, the value of C_L ranges between 20pf and 30pf, and the value of the ratio C1/C2 ranges between 1 and 2. The required frequency can be fine tuned by varying the value of C2. The value of C_L, derived from C1 and C2, depends on the required frequency, characteristics of the oscillator, and the crystal used.

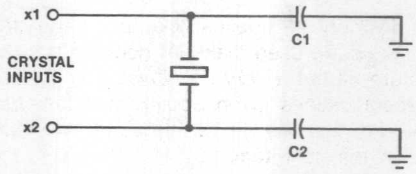

Figure 5. Circuit for Parallel Resonant Crystals

RECOMMENDED CIRCUIT FOR Z8581

Since the internal oscillator of the Zilog Z8581 is inverting, a parallel-resonant type crystal is recommended. The circuit configuration is shown in Figure 6. The preferred value of C_L is about 22pf. The preferred value of C1 and C2 is 33pf, which produces a ratio (C1/C2) of one. C2 can be made variable to fine tune the required frequency.

The output of one oscillator can also be connected to the crystal inputs of the second oscillator, using a 4700 ohms pull-up resistor at the output (Figure 6).

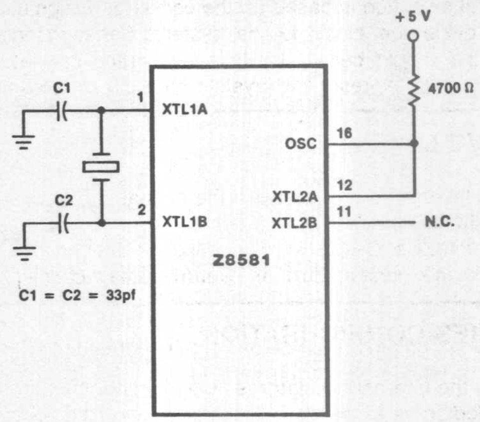

Figure 6. Circuit Configuration for Z8581

SPECIFICATIONS

For proper operation when using Zilog's Z8581, use a fundamental, parallel-type crystal. The following crystal specifications are suggested:

Frequency tolerance:	Application dependent
C_L, load capacitance:	Approximately 22pf (acceptable range is from 20-30pf)
Rs, equivalent-series resistance:	© 150 ohms
Drive level	
(for © 10 MHz crystal):	10 milliwatts
(for □ 10 MHz crystal):	5 milliwatts

Holder specifications are user-determined.

For frequencies lower than 4 MHz, the recommended holder type is HC-33/U (0.75″W × 0.765″H, 1.5″ lead length with specing of 0.486″).

For frequencies higher than 4 MHz, the recommended holder type is HC-18/U (0.435″W × 0.530″H, 1.5″ lead length with specing of 0.192″).

SUGGESTED VENDORS

The wide variety of applications and frequencies in which crystals are used makes it necessary to custom manufacture all but a very few crystal types. With the crystal specifications given above, most vendors can make the desired crystal even though it may not be a standard off-the-shelf item.

The following two vendors supply crystals to the specifications given above. The user is not limited to these vendors because these suppliers are among many suppliers who might meet your specifications.

Midland-Ross Corporation
NEL UNIT
357 Beloit Street
Burlington, WI 53105
Telephone: (414) 763-3591

CTS KNIGHTS, INC.
400 E. Reimann Ave.
Sandwich, Illinois 60548
Telephone: (815) 786-8411